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Evaluation of HiMAT Aircraft Landing Approach Lateral Control Gearing Using Simulation and a Visual Display

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ABS: The utility of a visual display when studying the influence of changes in lateral stick gearing gains on the Highly Maneuverable Aircraft Technology (HiMAT) vehicle handling qualities during simulated approaches and landings is investigated. The visual display improved the validity of the simulation and provided improved roll response cues for the HiMAT aircraft landing approach. A range of acceptable constant lateral stick gearing gains is found that provides adequate maneuverability and allows for precision moments.

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Evaluation of HiMAT Aircraft Landing Approach Lateral Control Gearing Using Simulation and a Visual Display

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SUMMARY

The highly maneuverable aircraft technology (HiMAT) aircraft is a remotely piloted research vehicle that has completed flight tests at NASA Ames Research Center's Dryden Flight Research Facility. A study was undertaken to focus on the utility of a visual display when studying the influence of changes in lateral-stick gearing gains on the HiMAT vehicle handling qualities during simulated approaches and landings. The results indicate that the visual display improved the validity of the simulation and provided improved roll response cues for the HiMAT aircraft landing approach. A range of acceptable constant lateral-stick gearing gains was found that provided adequate maneuverability and allowed for precision movements.

INTRODUCTION

The highly maneuverable aircraft technology (HiMAT) aircraft (fig. 1) is a remotely piloted research vehicle that has completed flight tests at NASA Ames Research Center's Dryden Flight Research Facility to provide data regarding transonic maneuverability. The HiMAT vehicle was launched from a B-52 aircraft and subsequently flown to a landing on the Edwards dry lakebed by a NASA test pilot in a ground-based cockpit. The vehicle was flown with cockpit display instruments until the landing approach phase at which time the camera aboard the aircraft was activated to provide the pilot with a television display of the approach.

During the operational phase of the HiMAT program, the lateral-stick gearing gain used in the aircraft approach was altered from a variable gain schedule derived from simulation to a constant gain schedule. The schedules were changed in response to pilot complaints about oversensitivity in the lateral stick that resulted in high workloads. Before the modified gain schedule was implemented into the primary control system (PCS), it was evaluated in the HiMAT simulator using an instrument landing approach (ILS) display; the schedule was found to be satisfactory. Postflight comments from HiMAT pilots indicated that the handling qualities during landing approach were significantly improved as a result of the modified gain schedule. A visual display for the simulator became available during the latter portion of the flight test program when simulation was no longer required to support the remaining flights.

The remotely piloted landing approach created a unique set of problems for the pilot. Lack of complete visual cues yielded insufficient information about sink rate, altitude, and runway position. The lack of motion feedbacks prevented the pilot from controlling the flightpath angle in turbulence, and increased the possibility of exceeding boundary limitations in the flight envelope. As a result, the pilot was sometimes forced to fly the vehicle in an open-loop fashion and rely on the cues from the instruments and the television monitor during approach and landing. The HiMAT landing approach evaluation was designed to focus on the utility of a visual display when studying the influence of changes in lateral-stick gearing gains on the HiMAT vehicle handling qualities during simulated approaches and landings. This study was undertaken to compare evaluations of pilots using the visual display and an ILS display in simulation with the results of actual flight tests.

NOMENCLATURE

c.g.	center of gravity
DA	differential elevon command, deg
DAP	lateral stick input, cm (in)
HiMAT	highly maneuverable aircraft technology
ILS	instrument landing system
KARI	aileron-rudder interconnect gain, deg/deg
KRD	lateral-stick gearing gain, deg/cm (deg/in)
KRP	roll-rate feedback gain, deg/deg/sec
M	Mach number
MAC	mean aerodynamic chord
P	roll rate, deg/sec
PCS	primary control system
PIO	pilot-induced oscillation
PR	pilot rating
$\bar{q}$	dynamic pressure, N/m^2 (lb/ft^2)
V	true velocity, m/sec (ft/sec)
VCAS	calibrated airspeed

SIMULATION FACILITY

The evaluation was conducted in the HiMAT fixed-base simulator (ref. 1) illustrated in figure 2. The instrument panel layout was identical to that used during flight. ILS glideslope indicators were used for all landing approaches, thus ensuring task consistency. The lateral stick had linear shaping, as shown in table 1. The location of the aircraft's center of gravity (c.g.) was maintained at 5 percent of the mean aerodynamic chord (MAC), a configuration that displayed poor lateral-directional handling qualities in flight. This c.g. location resulted in an unstable 2- to 3-percent static margin. The primary roll-control system shown in figure 3 illustrates the location of the lateral-stick gearing gain (KRD) with respect to the differential elevon command (DA) and the aileron-rudder interconnect gain (KARI).

The simulator was operated with an Evans and Sutherland Picture System (ref. 2) using a calligraphic monitor with a refresh rate of 60 Hz. The visual display provided the pilot with a viewing angle the same as that of the television display during flight. The onboard camera was positioned above the fuselage centerline with a 7° pitchdown orientation. This orientation was implemented into the visual display.

TEST PROCEDURE AND PROTOCOL

Standard procedures for the HiMAT aircraft flight approach using the primary control system included a transition by the pilot from ILS glideslope indicators to the television monitor when the vehicle was 6 to 9 km (3 to 5 mi) from touchdown. The pilots were asked to give handling qualities ratings and comments for both the ILS and the visual portions of the actual landing approach task. Landing speeds ranged from 180 to 190 knots and the maximum vertical velocity was 3 m/sec (10 ft/sec). These values were used as boundary limits in the evaluation.

The initial conditions of the simulated landing approach are shown in table 2. The aircraft was positioned with a lateral deviation of about 6° to the left of the horizontal glideslope (fig. 4). This required the pilots to use lateral stick inputs to intercept the glideslope. An alternative set of conditions, shown in figure 5, positioned the aircraft on the glideslope with no lateral deviation but at a lower altitude. This set of initial conditions allowed a greater number of approaches to be flown within a limited period of time (when time was at a premium). This change in initial conditions did not significantly affect the results. Figures 4 and 5 also illustrate the noseboom configuration as seen during flight from the onboard camera.

Four separate approach conditions were selected for the evaluation. The landing approaches were first conducted under ILS conditions and then repeated using the visual display. Each set of conditions was flown in both calm air and in random gusts. The calm conditions were representative of actual and simulated approaches flown by the HiMAT pilots. The random gusts were activated by a switch on the cockpit display panel that provided disturbances along the x, y, and z axes, each with a velocity of 0.91 m/sec (3 ft/sec). The gusts were washed out 46 m (150 ft) above the runway surface. The purpose of the random gust conditions was to evaluate the suitability of a particular gain under adverse conditions.

The lateral-stick gearing gain schedules used in the study consisted of five constant gains (KRD = 1.6 (4), 3.1 (8), 4.7 (12), 6.3 (16), 7.9 (20) deg/cm (deg/in)) shown in figure 6. The original gain schedule (for S.I. units, KRD = $33{,}931/\bar{q}$; for U.S. units, KRD = $1800/\bar{q}$) was used solely as a point of interest and had a variable range (KRD = 3.1 to 7.1 deg/cm (8 to 18 deg/in)). The original gain schedule was not used in the validation portion of the evaluation because it had been replaced with the modified gain in the actual flight test program. The six gain schedules were presented to the pilots in a random sequence for each combination of approach conditions (table 3). The pilots had no knowledge of the gain sequence.

Three NASA test pilots were selected for the evaluation. Pilot 1 had HiMAT flight experience with the modified gain schedule; pilot 2 had HiMAT flight experience with both the modified and the original gain schedules; and pilot 3 had no previous HiMAT flight experience, but had extensive handling qualities evaluation experience.

Following each approach, the pilots were asked to evaluate the lateral-directional handling qualities by using a Cooper-Harper rating scale (fig. 7). Each pilot was also asked to comment on the roll response and maneuverability of the vehicle, and on any tendency to overcontrol or cause lateral pilot-induced oscillation (PIO). Both the flight and simulation approaches were made without rudder inputs.

The HiMAT roll characteristics in simulation were documented at the conclusion of the evaluation. Figure 8 illustrates time-to-bank results for the constant gain schedules. The steady-state roll rate for a maximum lateral step input was 48 deg/sec at 250 knots.

RESULTS AND DISCUSSION

The constant gain schedules were flown in the evaluation under ILS and visual conditions in both calm and turbulent air. The handling qualities results presented in figures 9(a) to 9(d) illustrate distinct characteristic trends for increasing gains. Comparison of the visual and ILS calm-air graphs (figs. 9(a) and 9(c)) shows that lower gains were preferred with the visual display than with the ILS configuration. Conversely, higher gains were preferred with the ILS than with the visual display. This behavior is attributed to the apparent increase in response when visual display approaches were flown. This increase in response leads to overcontrol tendencies with higher gains. The visual display with gusts (fig. 9(d)) illustrates the need for greater control responsiveness in the presence of the apparently larger upsets relative to similar upsets under ILS conditions (fig. 9(b)). The effects of the turbulent disturbances were enhanced by the visual display, and were considered by the pilots to be a factor in the control power of the vehicle.

Figure 10 illustrates the pilots' average results for increasing gains. The ratings are fairly consistent at the lower gains, but at the higher gains pilot 2 indicated a greater preference for higher gearing gains than did pilots 1 and 3. Pilot 3 found the higher gains to be more undesirable than did pilots 1 and 2.

The averaged pilot ratings obtained from the ILS and visual portions of the HiMAT flight landing approaches (table 4) using the constant gain schedule were compared with corresponding simulation points from the calm-air ILS and visual display approaches that best represented actual flight conditions (fig. 11). The comparison of visual display results showed good correlation, indicating the potential of the visual display simulation for obtaining results comparable to those found in flight. ILS results showed reduced correlation between simulation and flight compared to the visual results (fig. 11). Lateral control activity for both the simulation and flight approaches compared satisfactorily, as indicated in figure 12. Conflicting scheduling of simulation prevented the acquisition of data from the same pilot (fig. 12). Therefore, a comparison of the relative control activity areas is only qualitative.

Because of the broadly defined limits of the HiMAT approach, the pilots were able to complete the required task under both nominal and adverse conditions. Determining an optimal range for constant lateral-stick gearing gains therefore became a choice between the pilots' ability to perform small precision corrections and to perform gross maneuvers. The pilots generally found the lower gains satisfactory for precision corrections throughout the task, although the aircraft was sluggish or insensitive in roll. The presence of such insensitivity became unacceptable in turbulence or in a situation during an actual approach that would require rapid maneuvering. The higher gains provided the maneuverability, but were oscillatory and had a tendency to result in overcontrol or in lateral PIO. This was apparent (figs. 9(c) and 9(d)) using the visual display under both calm and gust conditions. Therefore, the optimal range of constant lateral-stick gearing gain schedules had to provide adequate maneuverability and allow for precision corrections during the simulated HiMAT aircraft visual approach. Values of KRD between 2.4 and 3.1 deg/cm (6 and 8 deg/in) provided such requirements.

Pilot comments made after visual HiMAT vehicle flight approaches were consistent with those found in the visual simulation. Pilot 2 said that the constant gain (KRD = 1.6 deg/cm (4 deg/in)) was insensitive in roll during flight, which was consistent with his comments on the visual simulation. Pilot 1 said that the aircraft was sluggish in roll in the ILS simulation but acceptable in visual flight. With the use of the visual display simulation, pilot 1 noted improved roll response, although some sluggishness was still present. He felt the visual display provided significantly improved cues for the HiMAT approach, as did pilot 2. Pilot 3 stated that the visual display increased the apparent sensitivity of the gains and amplified large bank-angle excursions when compared with the ILS approaches. Pilot ratings and comments for all simulated approaches are presented in the appendix.

The original gain schedule was flown under the simulated flight conditions, but was not included in the evaluation results. The varying nature of the original gain schedule prevented the handling qualities ratings obtained for those particular approaches to be adequately compared (within the scope of the study) with the constant gain schedules. Based on actual flight experience, the original gain schedule was undesirable because of its oversensitivity in roll; as a result, it was replaced by the constant gain schedule.

CONCLUSIONS

The highly maneuverable aircraft technology (HiMAT) aircraft visual display landing approach simulation produced handling qualities results that are comparable to those found in flight for the constant lateral-stick gearing gain schedule (KRD = 1.6 deg/cm (4 deg/in)). The pilots felt that the capability of the visual display to provide an adequate representation of the HiMAT vehicle approach improved the validity of the simulation. Therefore, the use of the visual display can increase the simulation's effectiveness as a tool in flight test programs.

The HiMAT pilots stated that the visual display simulation provided improved cues regarding roll response for the HiMAT vehicle landing approach. Despite insensitivity, the lower gains were found to be satisfactory for precision corrections. The lower gain condition became unacceptable in the presence of turbulence. Although the higher gains provided adequate maneuverability, they were oscillatory and had a tendency to cause pilot overcontrol or lateral pilot-induced oscillation (PIO). A constant lateral-stick gearing gain between 2.4 and 3.1 deg/cm (6 and 8 deg/in) was found to provide adequate maneuverability and allow for precision movements during the simulated HiMAT visual approach.

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APPENDIX — PILOT RATINGS

(Responses refer to lateral-directional handling qualities)

PILOT 1		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
	ILS, calm	
1.6 (4)	5	Heavy lateral forces
3.1 (8)	4	Sluggish in roll
4.7 (12)	3	Good lateral response
6.3 (16)	4	Good lateral response
7.9 (20)	2	Good lateral response
$33{,}931/\bar{q}$ $(1800/\bar{q})$	4	Good lateral response
	ILS, gusts	
1.6 (4)	5	Sluggish response; heavy forces required
3.1 (8)	5	Sluggish response; heavy forces required
4.7 (12)	3	Good lateral response
6.3 (16)	3	Good; slight tendency to overcontrol
7.9 (20)	4	Seemed sluggish; slight tendency to overcontrol
$33{,}931/\bar{q}$ $(1800/\bar{q})$	3	Good lateral response

PILOT 1		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
	Visual display, calm	
1.6 (4)	4	Sluggish; slow roll response
3.1 (8)	3	Sluggish in response
4.7 (12)	4	Too sensitive; slow roll response
6.3 (16)	6	Too sensitive; continuous lateral PIO
7.9 (20)	5	Too sensitive; occasional lateral PIO
$33,931/\bar{q}$ $(1800/\bar{q})$	5	Too sensitive; occasional lateral PIO
	Visual display, calm (repeat)	
1.6 (4)	2.5	Sluggish, but no problem
3.1 (8)	2.5	Nice response
4.7 (12)	2.5	Nice response
6.3 (16)	4.5	Tendency to overcontrol at times
7.9 (20)	3.5	Tendency for PIO at flare
$33,931/\bar{q}$ $(1800/\bar{q})$	3	More sensitive than optimal gain
	Visual display, gusts	
1.6 (4)	5	Too insensitive
3.1 (8)	5	Large gust upsets; sluggish
4.7 (12)	6	Excessive roll upsets; overcontrol in roll
6.3 (16)	5	Overcontrol in roll
7.9 (20)	7	Too sensitive in roll; roll upsets caused by turbulence are excessive
$33,931/\bar{q}$ $(1800/\bar{q})$	6	Too sensitive in roll; roll upsets caused by turbulence are excessive

PILOT 2		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
ILS, calm		
1.6 (4)	4	Stick gearing too low
3.1 (8)	3.5	Stick gearing too low
4.7 (12)	2	Good damping; good response
6.3 (16)	3	Not as much spiral stability as run 1
7.9 (20)	3	Too sensitive; good for smooth air
$33{,}931/\bar{q}$ $(1800/\bar{q})$	3	Gain more responsive; better than run 4
ILS, gusts		
1.6 (4)	5	Low gearing for turbulence; more sensitivity required
3.1 (8)	3.5	More gearing required
4.7 (12)	4	Not responsive enough in roll
6.3 (16)	3	In ballpark; would prefer a little more sensitivity
7.9 (20)	3	Good stick force for aircraft
$33{,}931/\bar{q}$ $(1800/\bar{q})$	4	Higher gearing required

PILOT 2		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
Visual display, calm		
1.6 (4)	4	Too little gearing; good for calm day; unacceptable in turbulence
3.1 (8)	3	Stick gearing too low, good for calm conditions
4.7 (12)	3	Slightly less sensitive than optimum
6.3 (16)	2	Just right
7.9 (20)	4	Too sensitive
33,931/$\bar{q}$ (1800/$\bar{q}$)	3	Not enough gearing
Visual display, calm (repeat)		
1.6 (4)	4	Sluggish
3.1 (8)	3	Nice flying aircraft
4.7 (12)	2	No tendency to overcontrol
6.3 (16)	3	Little too much gearing
7.9 (20)	3.5	Too high gearing
33,931/$\bar{q}$ (1800/$\bar{q}$)	3	Gearing too low
Visual display, gusts		
1.6 (4)	5	Gearing too low
3.1 (8)	5	Gearing too low
4.7 (12)	3	Good lateral gearing
6.3 (16)	3.5	Little too sensitive
7.9 (20)	4	Too sensitive
33,931/$\bar{q}$ (1800/$\bar{q}$)	3	Satisfactory

PILOT 3		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
ILS, calm		
1.6 (4)	4	Sluggish; slow response; no overcontrol; large displacements required
3.1 (8)	3	Less than desired response; initially slow
4.7 (12)	2	No overcontrol; small precision movements possible
6.3 (16)	4.5	More sensitive, oversensitivity tends to reduce precision
7.9 (20)	6	Too responsive; tendency to overcontrol with visual display
$33{,}931/\bar{q}$ $(1800/\bar{q})$	2	No problems; initially thought it would be more sensitive
ILS, gusts		
1.6 (4)	5	Needs improvement; slow response
3.1 (8)	3	Controllable; satisfactory; good
4.7 (12)	3	Achieves desired performance better
6.3 (16)	6	Tendency to overcontrol; hard to separate turbulence
7.9 (20)	6	Not satisfactory; too sensitive; overcontrol
$33{,}931/\bar{q}$ $(1800/\bar{q})$	4.5	Initial response too fast; performance deteriorated by turbulence

PILOT 3		
KRD, deg/cm (deg/in)	Cooper-Harper ratings	Comments
Visual display, calm		
1.6 (4)	3	Slow; very solid in roll; good for task, but unresponsive
3.1 (8)	2	Solid laterally with display; visual display heightens less responsive gains
4.7 (12)	6	Small amplitude lateral PIO
6.3 (16)	6	Oscillatory; problem with precision laterally, yet tolerable for task
7.9 (20)	7	Didn't like it; overcontrol; strong PIO tendency would break up aircraft
$33{,}931/\bar{q}$ $(1800/\bar{q})$	3	Tendency to overcontrol at times
1.6 (4)	3	(Repeat) Can split centerline with display, yet heavy forces are required for stick
$33{,}931/\bar{q}$ $(1800/\bar{q})$	2	(Repeat) More responsive than run 7. Not much compensation required
Visual display, gusts		
1.6 (4)	4.5	Low control power laterally; visual display very sensitive; achieve better performance with lower gain, yet too unresponsive
3.1 (8)	5	Not responsive enough with turbulence
4.7 (12)	3	Good aircraft stability, response
6.3 (16)	5	Turbulence is more upsetting than without display
7.9 (20)	8	Barely controllable; overresponsive; bank angle excursions with display induce "cross-eyed" vision
$33{,}931/\bar{q}$ $(1800/\bar{q})$	5	Bank angle not stable; turbulence upsets control power

REFERENCES

1. Evans, Martha B.; and Schilling, Lawrence J.: The Role of Simulation in the Development and Flight Test of the HiMAT Vehicle. NASA TM-84912, 1984.

2. Mantle, M.; and Mortenson, D.: Picture System 2/PDP-11 Reference Manual. Second ed. Evans and Sutherland Computer Corp., E and S 901130-001 A1, 22 Nov. 1977.

TABLE 1. — HiMAT CONTROL STICK CHARACTERISTICS

Stick	Force, N/cm (lb/in)	Breakout, N (lb)
Lateral	8.8 (5.0)	11.6 (1.6)
Longitudinal	7.0 (4.0)	13.3 (3.0)

TABLE 2. — SIMULATED LANDING APPROACH INITIAL CONDITIONS

Altitude, m (ft)	1676 (5500)
Range, km (nmi)	16 (8.4)
Lateral deviation, deg	6
Angle of attack, deg	2
Angle of sideslip, deg	2
VCAS, knots	250
$\bar{q}$, N/m^2 (lb/ft^2)	10,007 (209)
M	0.42
c.g., percent MAC	5
Fuel, percent	50

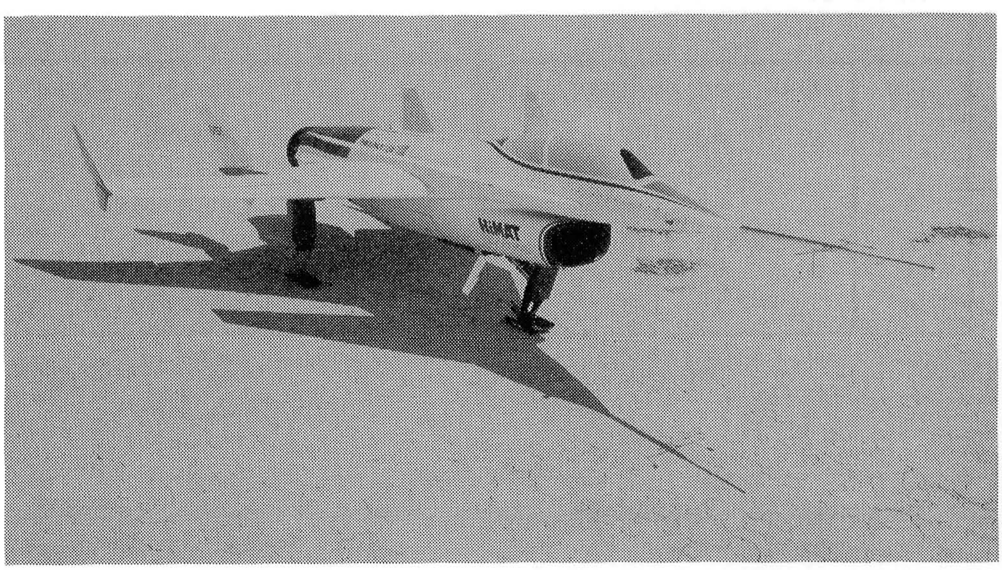
TABLE 3. — GAIN SCHEDULE SEQUENCE VISUAL AND ILS APPROACHES

Calm Air		Gusts	
Run	KRD, deg/cm (deg/in)	Run	KRD, deg/cm (deg/in)
1	4.7 (12)	1	3.1 (8)
2	1.6 (4)	2	7.9 (20)
3	6.3 (16)	3	33,931/$\bar{q}$ (1800 $\bar{q}$)
4	33,931/$\bar{q}$ (1800/$\bar{q}$)	4	6.3 (16)
5	7.9 (20)	5	1.6 (4)
6	3.1 (8)	6	4.7 (12)

TABLE 4. — HiMAT AIRCRAFT LANDING APPROACH FLIGHT RATINGS AND COMMENTS

(5 percent of MAC c.g. configuration; responses refer to lateral-directional handling qualities)

Pilot	Flight	KRD, deg/cm (deg/in)	Cooper-Harper rating		Comments
			ILS portion	Television portion	
2	H1-10-18	$33,931/\bar{q}$ ($1800\ \bar{q}$)	6	6	Very prone to pilot over-control of centerline; would have needed to go to backup in turbulent cross-wind (PR = 7)
2	H2-6-8	1.6 (4)	3	4	Much better than previous original gain handling qualities; television portion of the approach was insensitive in roll
2	H2-8-8	1.6 (4)	3	3	Low workload; much more flyable than prior to development of constant gains
1	H2-10-14	1.6 (4)	4	3	Sluggish in roll on simulator; liked it in roll in flight
1	H2-11-15	1.6 (4)	2	2	Nice control forces and response



ECN 9953

Figure 1. HiMAT aircraft.

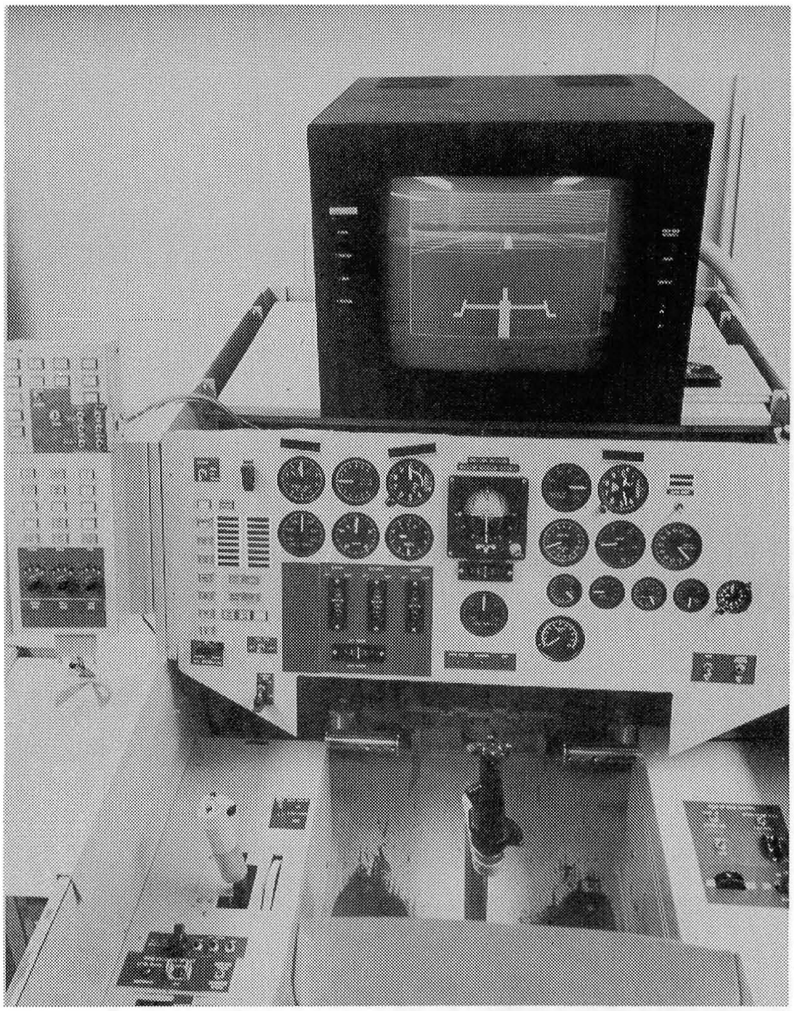


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Figure 2. HiMAT simulation cockpit.

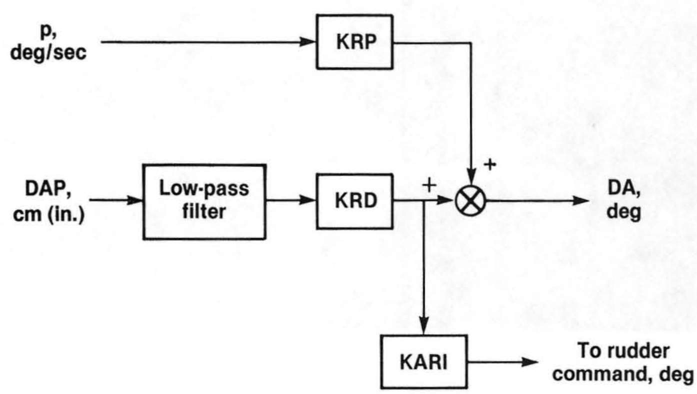

Figure 3. HiMAT vehicle primary roll control system.

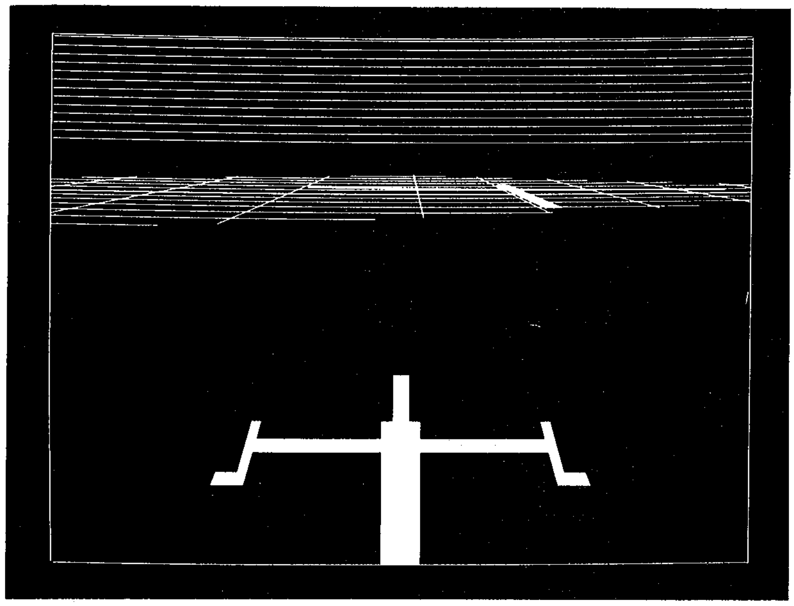

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Figure 4. Simulated landing approach initial conditions; visual display, lateral offset.

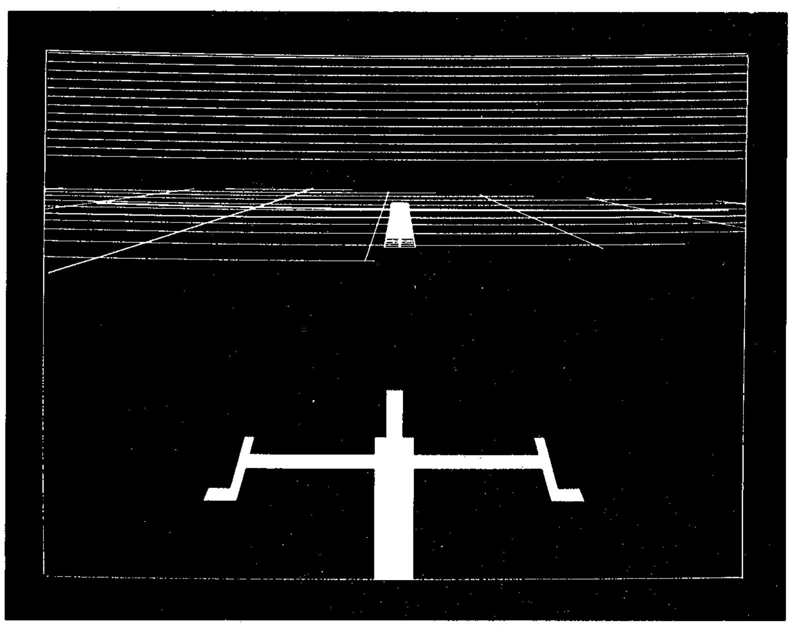

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Figure 5. Simulated landing approach conditions on glideslope.

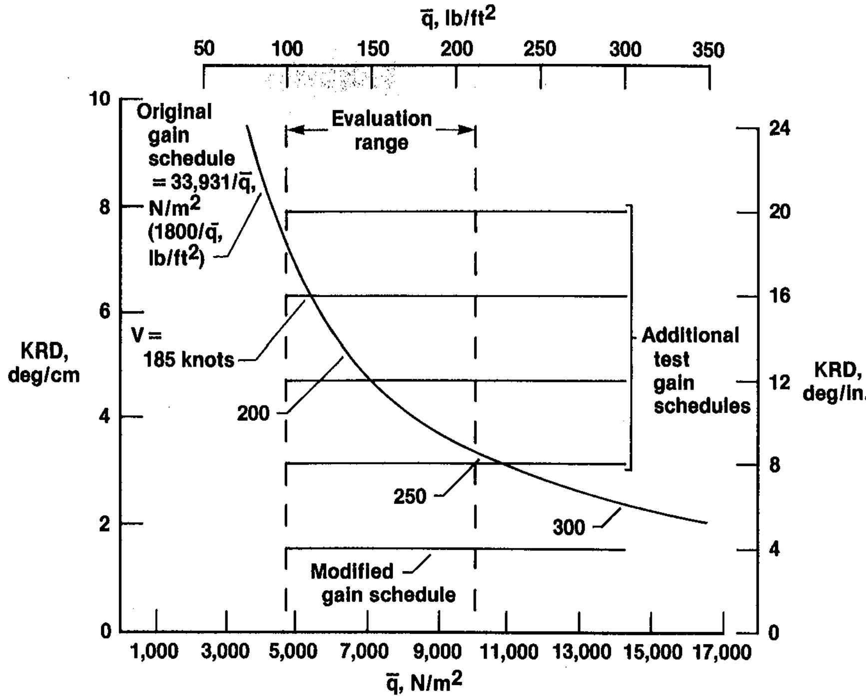


Figure 6. HiMAT lateral-stick gearing gain schedules. Mach number < 1.0; c.g. = 5 percent of MAC; and maximum lateral stick = ±10.8 cm (±4.25 in).

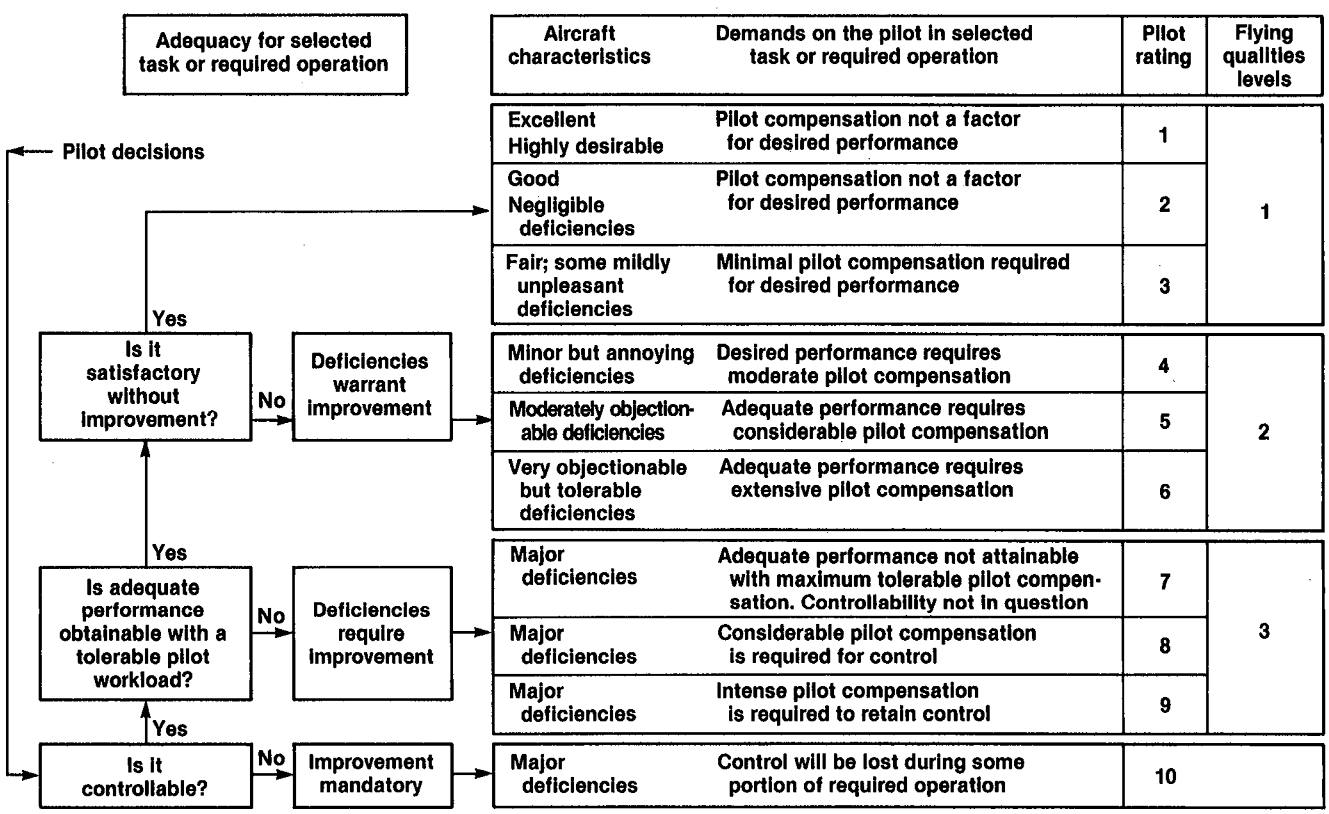


Figure 7. Cooper Harper pilot opinion rating.

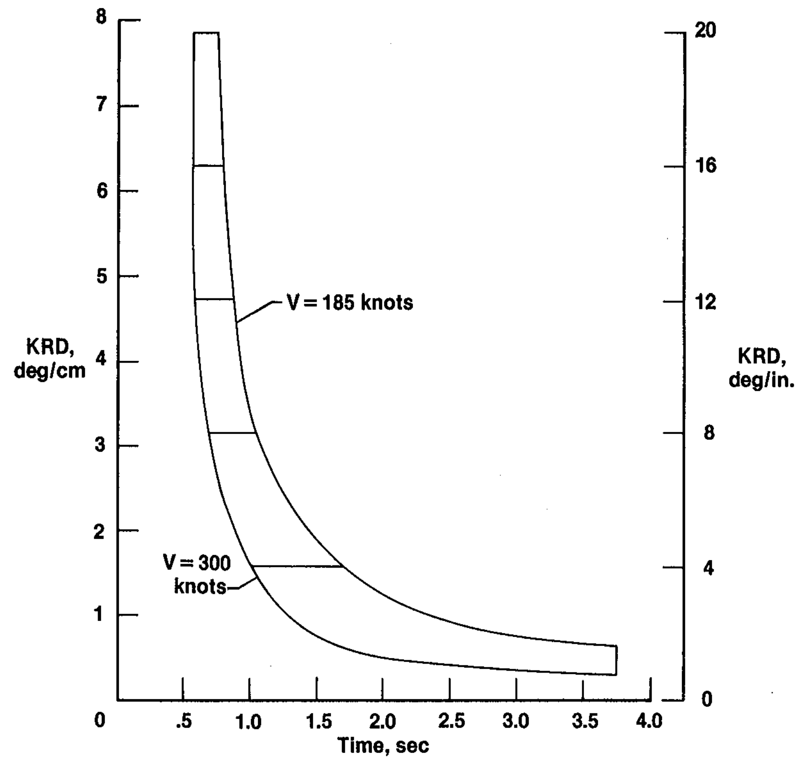
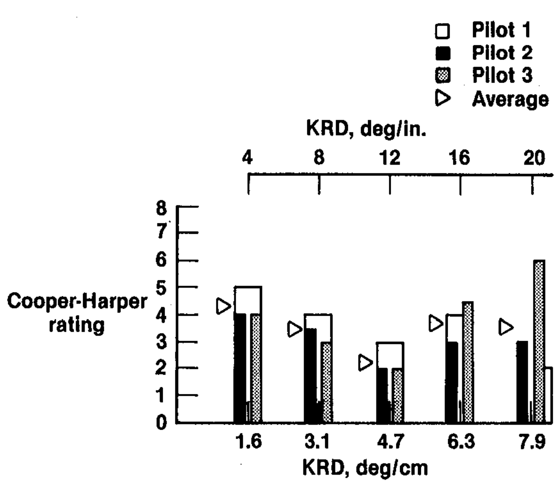
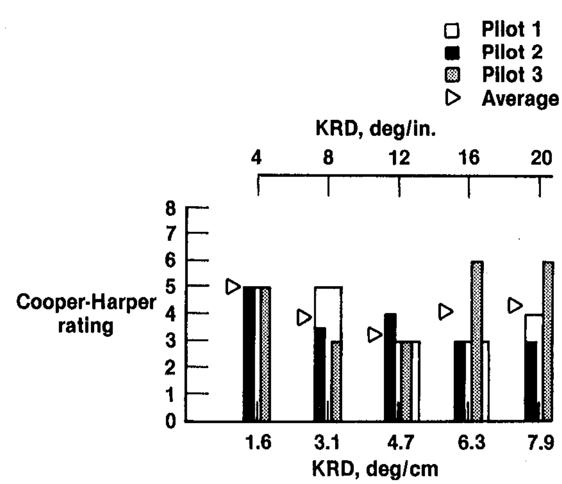


Figure 8. HiMAT simulation landing approach time to 30° bank. Altitude = 1219 m (4000 ft); maximum lateral stick = ±10.8 cm (±4.25 in).

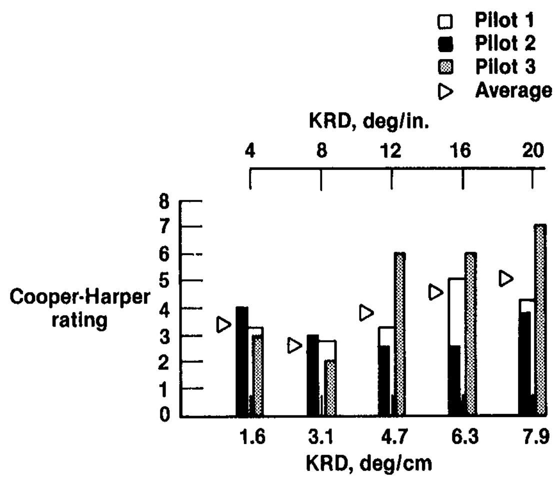


(a) ILS, calm.

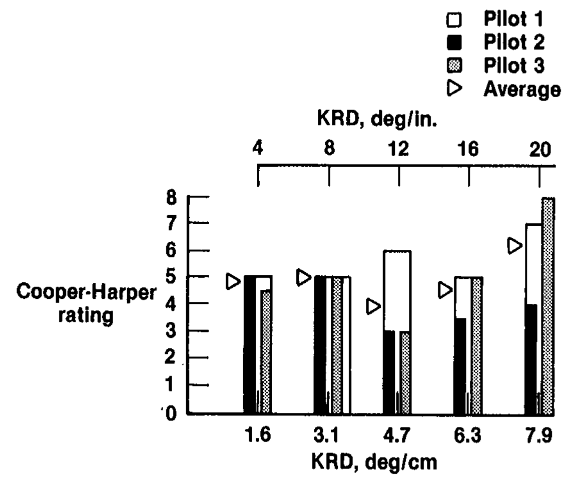


(b) ILS, gusts.

Figure 9. Simulation handling qualities results.



(c) Visual display, calm.



(d) Visual display, gusts.

Figure 9. Concluded.

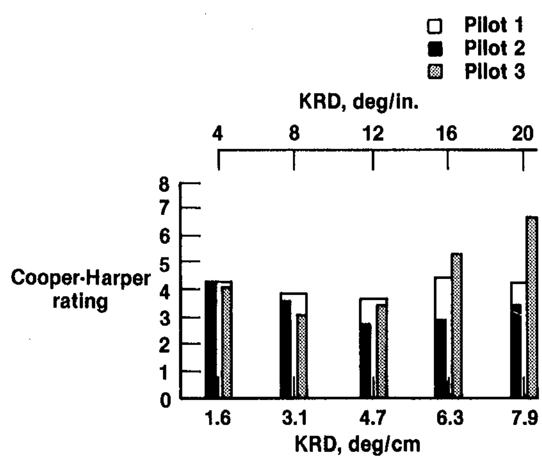
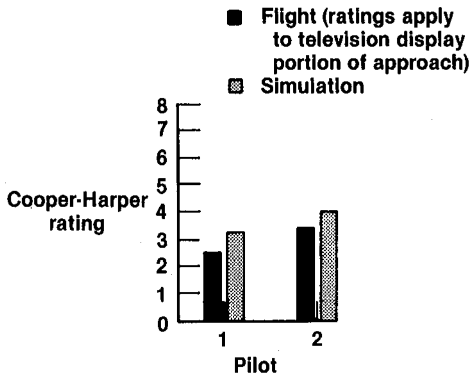
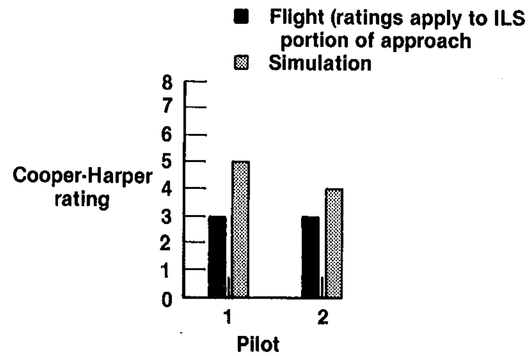


Figure 10. Averaged handling qualities results for all conditions.



(a) Visual display.



(b) ILS display.

Figure 11. Comparison of flight and simulation results for HiMAT approach and landing. KRD = 1.6 deg/cm (4 deg/in); calm air.

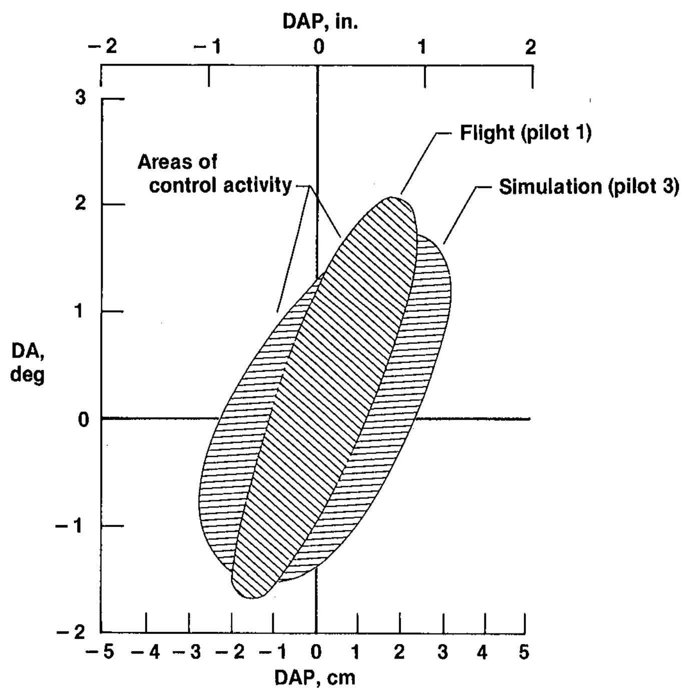


Figure 12. Comparison of lateral control activity for HiMAT landing approach; c.g. = 5 percent of MAC.

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16. Abstract

The highly maneuverable aircraft technology (HiMAT) aircraft is a remotely piloted research vehicle that has completed flight tests at NASA Ames Research Center's Dryden Flight Research Facility. A study was undertaken to focus on the utility of a visual display when studying the influence of changes in lateral-stick gearing gains on the HiMAT vehicle handling qualities during simulated approaches and landings. The results indicate that the visual display improved the validity of the simulation and provided improved roll response cues for the HiMAT aircraft landing approach. A range of acceptable constant lateral-stick gearing gains was found that provided adequate maneuverability and allowed for precision moments.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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